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Experimental Report on the Nano-identation Testing of Textured Stainless Steel 904 L and 316 L

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Abstract

The hardness of grain boundaries with or without twinning boundaries have impact on mechanical behaviors of stainless steels. In this paper, Nanoindentation experiments were conducted by using a Triboindenter instrumented nanoindenter (Hysitron, USA), calibrated on pure aluminum and silica on the deformed stainless steel 904L and 316L, respectively. It can be seen that the hardness distributions are all random in those grains, no matter with or without twinning. Grain boundaries with twinning boundaries is higher than that without twinning boundaries for 904L SS, it should be the effect of twin boundaries existence. No obvious difference can be observed between the hardness distribution of 316L SS. The texture evolution of rolled 904L stainless steel which is austenitic phase were symmetrically at room temperature to different reductions, i.e., 0%, 20%, 40%, 60%and 80% were also researched, the result suggest a strong influence of the micromechanical incompatibility of the austenite phases on the texture evolution .

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Keywords: Nanoindentation; Stainless Steel; Grain Boundary;Twinning Boundary; Texture

1. Introduction

While the main driving force for the development of austenite stainless steels has been the super high corrosion resistance, their enhanced mechanical properties, i.e., excellent combination of strength and toughness, have also

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been obtained in many service environments (at low, ambient and elevated temperatures). Understanding and predicting microstresses and preferred orientation in metals and alloys subjected to various deformation modes is a prerequisite for successfully developing and evaluating some engineering components. In the past decade, much attention has been paid to simulating the anisotropic micromechanical behaviors by using various numerical and analytical models [1].

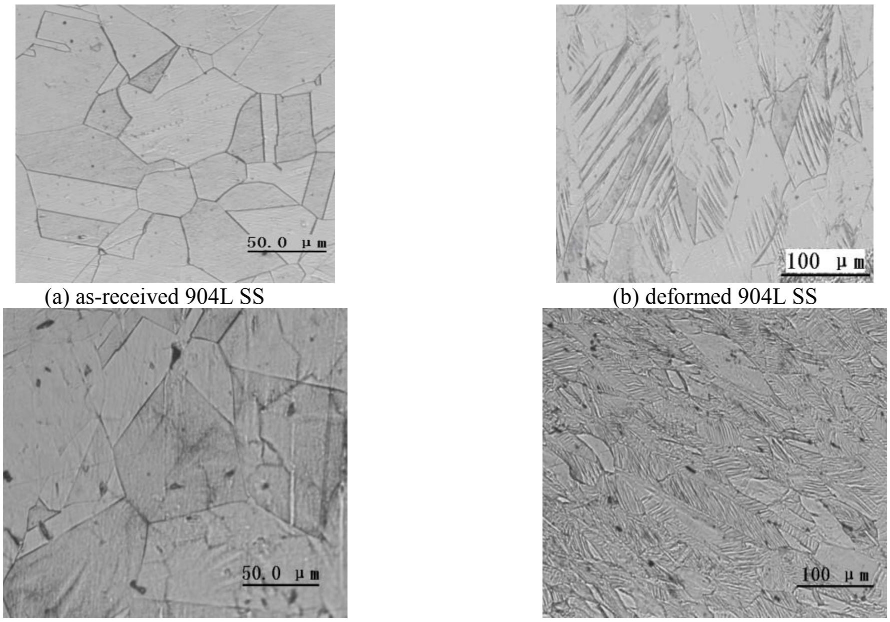
Models for texture evolution will be presented and analyzed. Undoubtedly, while it is important to at least have a measurement of the texture, it is even more important to be able to predict it for several reasons. Reliable texture prediction is required for understanding and prediction of anisotropic mechanical behavior. It can help in designing for better control and energy efficiency during forming processes. (‘‘Texture control” is widely regarded as one of the most important applications of texture modeling.) Texture prediction can also be used as a tool for determining dominant microscale mechanisms or certain characteristics of the applied deformation. For instance, deformation twins which reorient parts of the grain and result in large misorientation across their boundaries can be detected by a texture measurement [2,3]. As another example, it has also been used to help isolate the mechanisms in the creep of SPD processed aluminum [4].

The objective of this paper was to study the difference of the hardness distribution between twin boundaries and grain boundaries. Knowledge of the mechanisms of the texture evolution of rolled 904L stainless steel which is austenitic phase were symmetrically at room temperature to different reductions, mechanical properties are significant to the theory and industrial production to broaden the product range and gain a distinct improvement of the mechanical properties of the final products.

2. Experimental and discussion

2.1 Nanoindentation experiments

The optical micrographs of two kinds of stainless steel, 904L and 316L, are showed in Fig.1. It can be observed that the microstructures of the stainless steel changed obviously after tensile test. At the strain of 20%, both twinning and slip bands exist in the deformed steels.



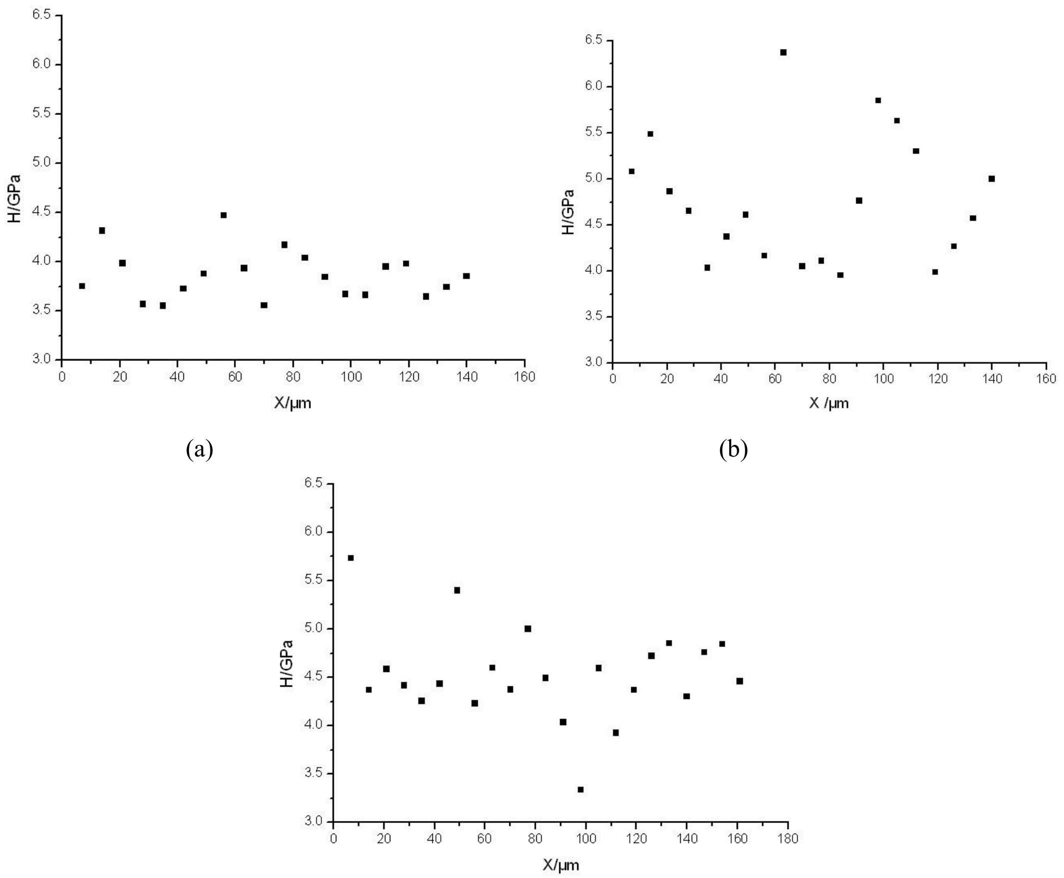
(a) as-received 904L SS (b) deformed 904L SS

(c) as-received 316L SS (d) deformed 316L SS

Fig. 1 Optical micrographs of 904L and 316L stainless steel, as-received and tensile to 20% .

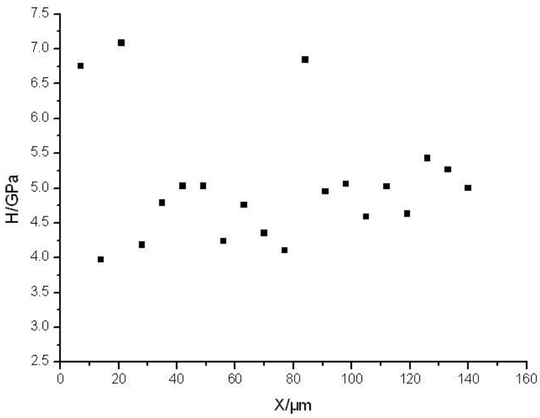
Nanoindentation experiments were conducted by using a Triboindenter instrumented nanoindenter (Hysitron, USA), calibrated on pure aluminum and silica. Fig.2 and Fig.3 show that the hardness distribution along test displacement of the 904L and 316L, respectively. In both figures, (a) is obtained from the grains without twinning, while both (b) and (c) describe the hardness for testing at the positions near the twin boundaries. It can be seen that the hardness distributions are all random in those grains, no matter with or without twinning. But the hardness of (b) and (c) are higher than (a) in Fig.2, it should be the effect of twin boundaries existence. The hardness of 316L SS ranges from 2.5 GPa to 7.2 GPa, as showed in Fig.3, no obvious difference can be observed between the hardness distribution as shown in (a) and (b)(c). Because the nanoindentation probe moved along a straight line during the measurement, the twin boundaries are not aligned strictly, hardness measurements at the points located exactly on the twin boundary might not be achieved (or the effect zone of twins is very large). As there is still a large variation of measured hardness among the grains without twinning, the effect of twin boundaries may still exist. This is due to the specified alignment of the twin boundaries, which was not displayed in the optical micrographs. In this way, other technique such as synchrotron XRD technique should be used for characterizing the effect of twin boundaries on the mechanical properties.

Printscreen of the nanoindentation is also attached in Fig.4.

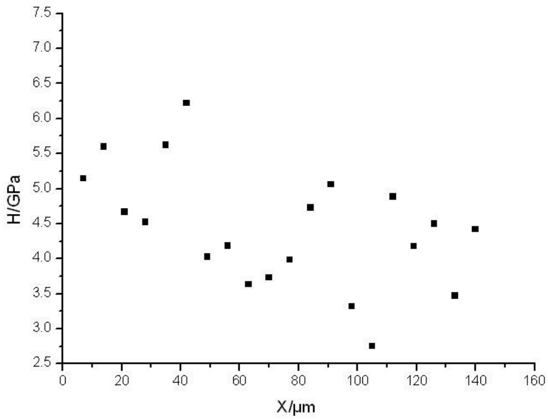


(a) (b) (c)

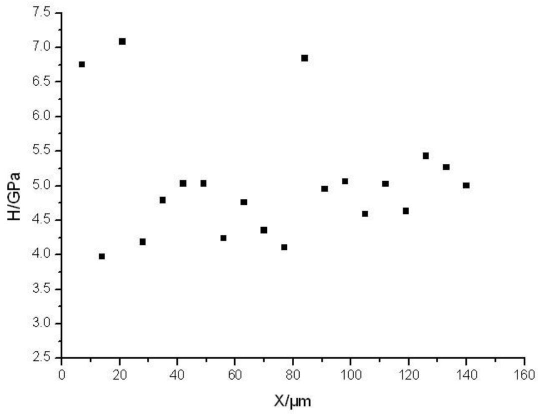
Fig.2 Hardness distributions in the grains of (a) without twinning; and (b), (c) around twin boundaries of 904L SS along a measurement line



(a)

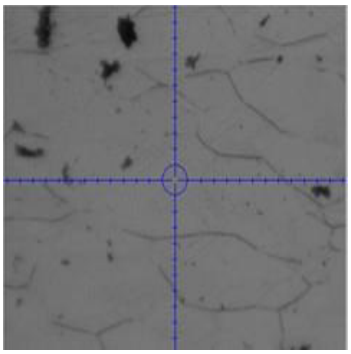


(b)

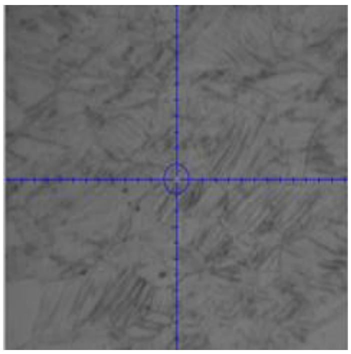


(c)

Fig.3 Hardness distributions in the grains of (a) without twinning; and (b), (c) around twin boundaries of 316L SS along a measurement line.



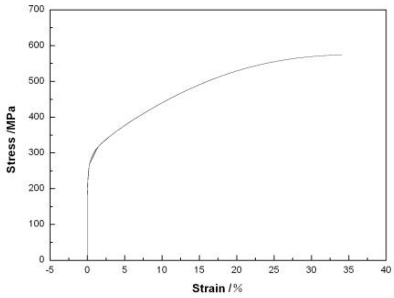
(a)



(b)

Fig.4 Printscreen of the nanoindentation for (a) 904L and (b) 316 stainless steel

From Fig.5 and Fig.6, we can see that at the same strain rate, the fracture strength, yielding strengh and total strain for 316L stainless steel are larger than that of 904L stainless steel.



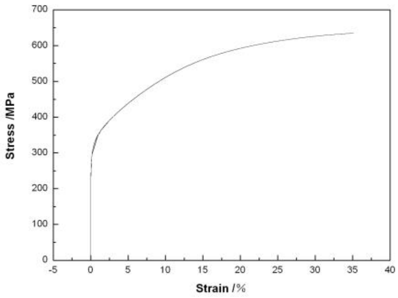


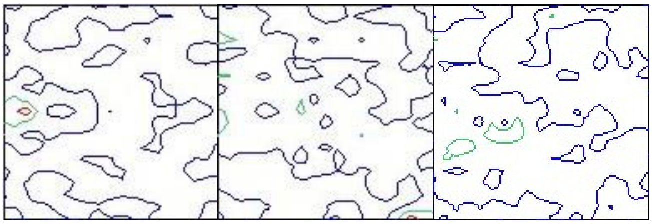
Fig.5. Stress vs. Strain curves for the SS904L

Fig.6. Stress vs. Strain curves for the SS316L

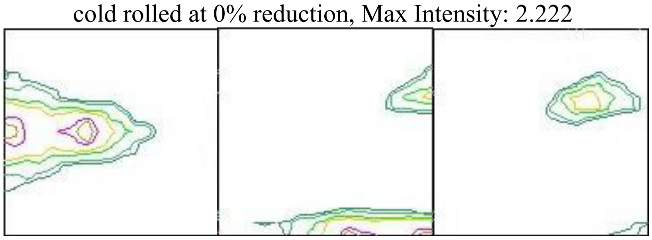
2.2 Textures evolution of rolled 904L stainless steel

As-received materials of 904L stainless steel which is austenitic phase were symmetrically rolled at room temperature to different reductions, i.e., 0%, 20%, 40%, 60%and 80%. The rolling processes were divided into many steps so as to ensure homogeneous deformation and to avoid generating a large quantity of heat in each step. Five plate-like specimens were cut from the above cold rolled materials parallel to the rolling direction of the as-received material Subsequently, X-ray diffraction was performed to measure rolling textures for those specimens.

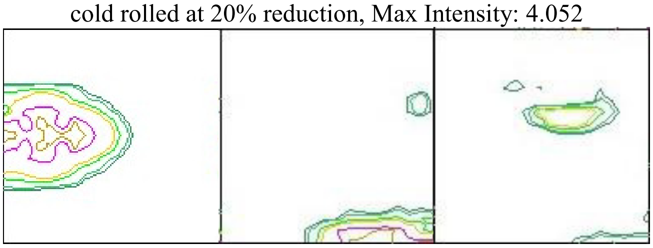
The experimental ODF sections (with φ2 = 0°, 45°, and 65°) are shown in Fig. 7 respectively.



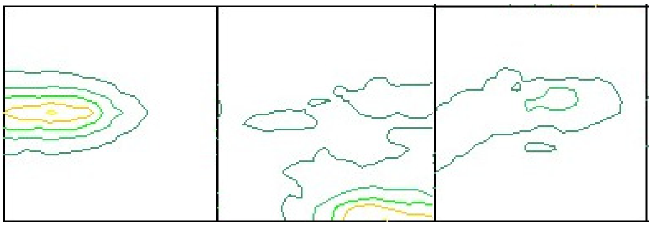
cold rolled at 0% reduction, Max Intensity: 2.222



cold rolled at 20% reduction, Max Intensity: 4.052



cold rolled at 40% reduction, Max Intensity: 4.237


cold rolled at 60% reduction, Max Intensity: 9.302

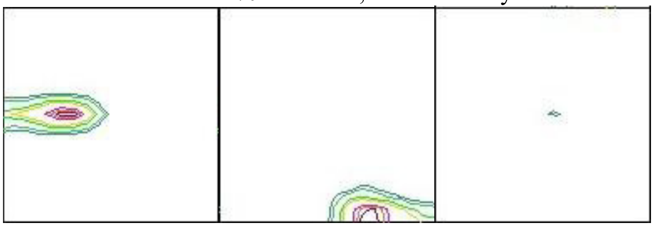

cold rolled at 80% reduction, Max Intensity: 11.333

Fig. 7 Texture evolution of the 904L stainless steel during cold rolling .

To clarify texture evolution of the austenitic phase during deformation, the measured orientation densities along the α fiber composing of the {011}<100> (Goss) and {011}<211> (Brass) components, and the τ fiber composing of the {001}<110> (Rotated-cube), {112}<111> (Copper) and Goss components are presented as functions of the Euler angles φ1 and Φ, respectively, in Fig. 1. As can be seen in the Fig.1, the texture of cold rolled at 0% reduction as-received specimen is very uniform, only a weak {011}<100> (Goss) and {011}<211> (Brass) components can be observed. When the rolling reduction below 60%, Goss and Brass textures are the main components in the 904L stainless steel. while {011}<211> (Brass) is continuously strengthened during this period and starts to dominate over all the other components with the further increase of reduction. At 80% reduction, very strong Brass component could be identified at φ2(0°, 45°,65°). This may theoretically suggest a strong influence of the micromechanical incompatibility of the austenite phases on the texture evolution [5].

Actually, I think I only find a weak Goss in the as-received specimen. And the Brass can be observed when the sheet rolled of 20% reduction. Both of Goss and Brass intensities are increasing with the increase of reduction. If severe deformation is applied, 60% and 80% reduction, the texture evolution from the { 1 1 0 }< 1 -1 2 > Brass shift into (0 1 1)[4 -1 1] and (0 1 1)[3 -1 1]. … S…

3. Summary and conclusions

In summary, Nanoindentation experiments and tensile tests of of two kinds of stainless steel 904L and 316L as well as textures evolution of rolled 904L stainless steel were investigated. Based on the experimental results and discussion, it is concluded as follows:

1. the hardness distributions are all random in those grains, no matter with or without twinning.
2. grain boundaries with twinning boundaries is higher than that without twinning boundaries for 904L SS
3. no obvious difference can be observed between the hardness distribution of 316L SS
4. a strong influence of the micromechanical incompatibility of the austenite phases on the texture evolution .
5. at the same strain rate, the fracture strength, yielding strengh and total strain for 316L stainless steel are larger than that of 904L stainless steel.

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